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RESEARCH DEPARTMENT

A method of measuring the specific acoustic impedance of membrane-type bass absorbers

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A METHOD OF MEASURING THE SPECIFIC ACOUSTIC IMPEDANCE OF MEMBRANE-TYPE BASS ABSORBERS

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(1965/33)

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October 1965 Research Report No. B-087

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A METHOD OF MEASURING THE SPECIFIC ACOUSTIC IMPEDANCE OF MEMBRANE-TYPE BASS ABSORBERS

SUMMARY

This report describes a simple method of measuring the specific acoustic impedance of membrane-type bass absorbers, i.e. of absorbers which consist of a vibrating membrane, the mass of which resonates with the stiffness of the fixed mass of air enclosed behind the membrane. Impedance measurements made by this method are compared with those obtained in an orthodox standing-wave tube.

1. INTRODUCTION

The type of bass absorber in most common use in the BBC consists of a closed box whose exposed surface is a vibrating membrane with high mechanical damping such as roofing felt,, or a panel of a hard material such as hardboard with a layer of roofing felt glued to its under side. Maximum absorption occurs at the frequency at which the mass of the membrane resonates with the stiffness of the air. The resonance frequency can be altered by altering the depth of the air space or the mass of the membrane.

The normal method of measuring sound absorption coefficients is by the use of a reverberation room. These measurements require 100 ft^2 (9·3 m^2) of sample material and clearly cannot be applied to absorbers installed in a studio.

Now it has been shown[1] that the maximum absorption at resonance is obtained when the real part of the acoustic impedance of the absorber is equal to the real part of its radiation impedance. Hence it would appear that a simple means of measuring the acoustic impedance of absorbers would be of assistance in attempting to measure their behaviour.

It has been customary to measure acoustic impedance indirectly by measuring the standing wave ratio and the distances from the termination to successive minima in a standing wave tube in which the absorber acts as the termination. From the two sets of readings the acoustic impedance can be calculated.[2] This method is tedious and has the great disadvantage that it cannot be used for measurements of acoustic impedance at studio sites.

The method described in this report has been devised to obviate these two difficulties when dealing with the types of absorbers described above. It is applicable only to the type of absorber in which a constant enclosed mass of air is compressed and expanded by vibration of a membrane or panel which forms the face of the enclosure.

2. THEORETICAL

The complex specific acoustic impedance Z_a of a specimen is defined by

$$Z_a = \frac{p_i}{v} \qquad (1)$$

where p_i is the incident pressure and v is the velocity of motion. For simple harmonic motion, the velocity, using steady-state terminology, may be written in terms of displacement, x, as

$$v = j\omega x \qquad (2)$$

Thus

$$Z_a = \frac{p_i}{j\omega x} \qquad (3)$$

For an absorber of cross sectional area, A, depth D, (Fig. 1), a change in volume dV_o is produced by a displacement, x, of the membrane given by

$$dV_o = -xA$$

or

$$x = -\frac{dV_o}{A} \qquad (4)$$

The displacement x may be expressed in terms of pressure as follows.

Assuming adiabatic expansion and compression of the fixed mass of air initially occupying the volume V_o at pressure P_o, we have from the gas laws

$$P_o V_o^{\gamma} = K \qquad (5)$$

where γ is the ratio of the specific heat of air at constant pressure to that at constant volume, and K is a constant.

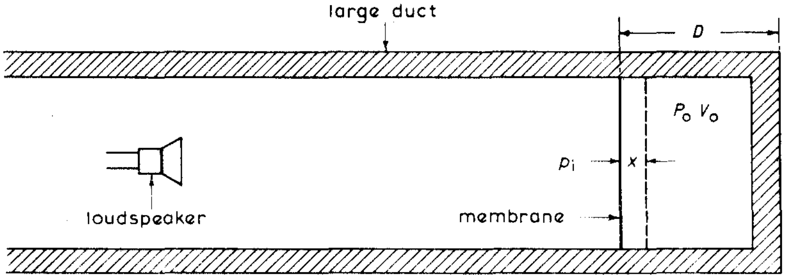

Fig. 1 - Diagram of a Membrane Absorber mounted in a Duct

Taking total differentials in equation (5)

$$P_o \gamma V_o^{\gamma-1} dV_o + V_o^{\gamma} dP_o = 0$$

whence
$$dV_o = -\frac{V_o dP_o}{\gamma P_o} \tag{6}$$

Substituting from (6) into (4)

$$x = \frac{V_o}{A}\frac{dP_o}{\gamma P_o}$$

or
$$x = D\frac{p}{P_o\gamma} \tag{7}$$

where p is the instantaneous value of the excess pressure dP_o.

Using this expression for x in equation (3) gives

$$Z_a = \frac{p_i}{p}\frac{\gamma P_o}{j\omega D} \tag{8}$$

Thus a measurement of the complex ratio p_i/p will give the complex specific acoustic impedance of an absorber of depth D at the frequency $\omega/2\pi$.

$$\text{if } \left|\frac{p_i}{p}\right| = r$$

$$\frac{p_i}{p} = re^{j\theta}$$

where θ, the relative phase of p_i and p, may be measured directly by a phase meter.

Equation (8) may therefore be rewritten:

$$Z_a = r\, e^{j(\theta - \pi/2)} \frac{P_o}{\omega D}$$

Thus the phase angle of the acoustic impedance is $\theta - \pi/2$.

3. EXPERIMENTAL RESULTS

3.1. Plane Wave Measurements

Initial measurements were made in a low frequency travelling wave tube made of brick and concrete and of cross section 2 ft × 2 ft 6 in (610 mm × 760 mm). A brick wall was built across the tube and various membranes were mounted a distance of 10 in (250 mm) in front of the brick wall, in such a way that the air space between the membrane and the wall was sealed. A calibrated microphone was placed inside the air space near to the surface of the membrane and a second calibrated microphone was mounted on a moveable carriage to enable pressure measurements to be taken at all points from the surface of the membrane to the sound source. The standing wave ratio and the distances from the membrane surface to successive minima were measured at several frequencies. From these standing-wave tube measurements the complex specific acoustic impedance was calculated.

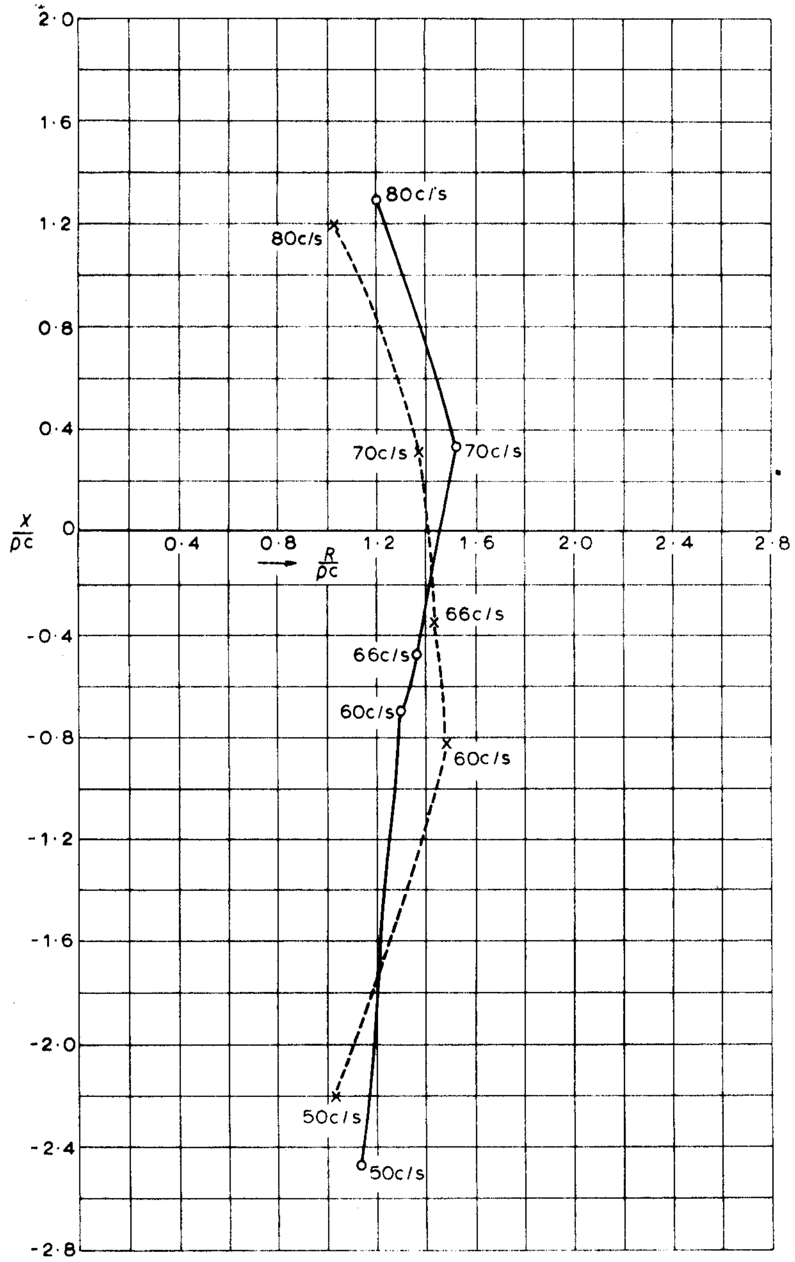

Fig. 2 - Impedance locus of steel sheet coated with Aquaplas

o———o Normal impedance tube method x- - - - - -x Proposed method

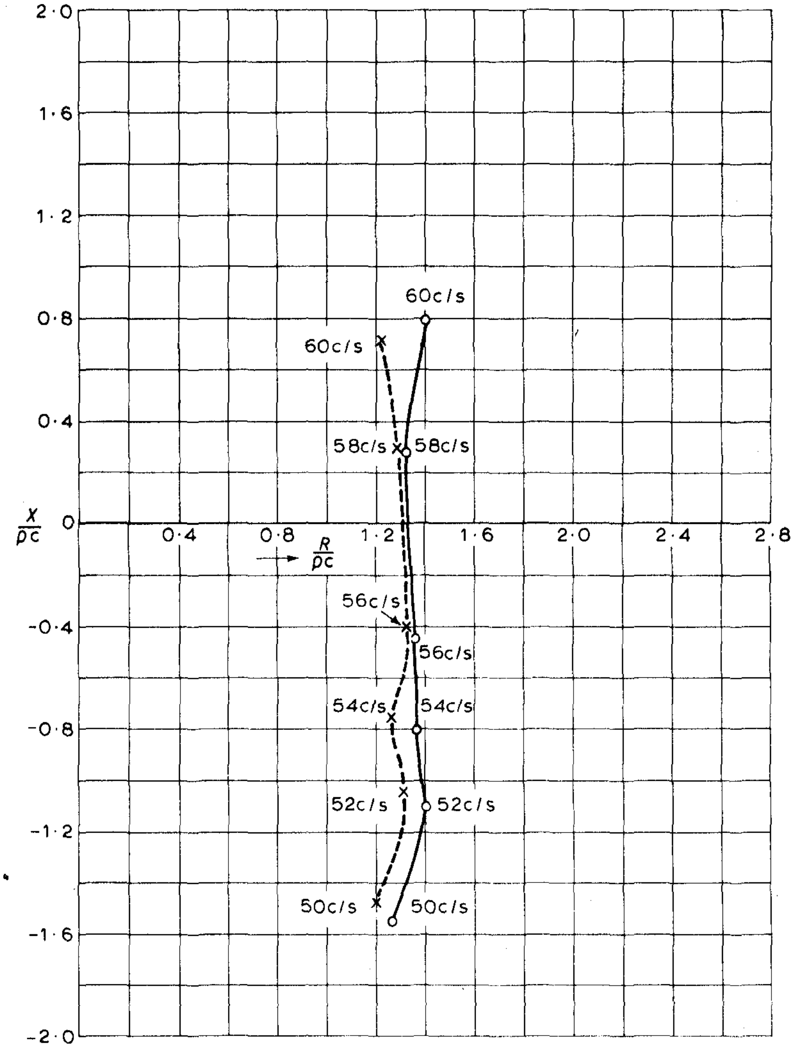

Fig. 3 - Impedance locus of 10 in (250 mm) deep bonded absorber

o——o Normal impedance tube method x——x Proposed method

Alternatively the ratio of the incident pressure to the internal pressure i.e. p_i/p and the difference in phase of the two pressures were measured. From these two readings the specific acoustic impedance Z_a was again calculated.

Figures 2 and 3 show the specific acoustic impedance loci obtained by both the above methods for two specimens. Fig. 2 shows the locus for a sheet of steel coated with aquaplas over a 10 in (250 mm) air space and Fig. 3 shows the locus obtained for a 10 in (250 mm) deep bonded absorber in which the membrane consists of a sheet of roofing felt bonded to one of 1/8 in (3 mm) hardboard. It will be seen that the two methods agree reasonably well.

3.2. Random Incidence Measurements

In order to investigate the effectiveness of the method for random incidence, a roofing felt membrane was mounted on a 7 in (180 mm) deep wooden box whose external dimensions ensured a close fit in the low frequency duct. The impedance locus was obtained using the proposed simple method with the absorber acting as a termination to the duct. The absorber was then moved into a room which has a reverberation time of 0•3 secs. A loudspeaker was placed 3 ft (1 m) in front of the absorber which stood on the floor spaced away from the wall. The pressure incident on the membrane and the internal pressure were measured and their relative phases noted. From these readings the impedance locus was obtained.

It will be seen from Fig. 4 curves (*a*) and (*b*) that both these measurements show a pronounced secondary resonance. It was thought that the secondary resonance was due to vibration of the rear of the box and this was confirmed by accelerometer measurements.

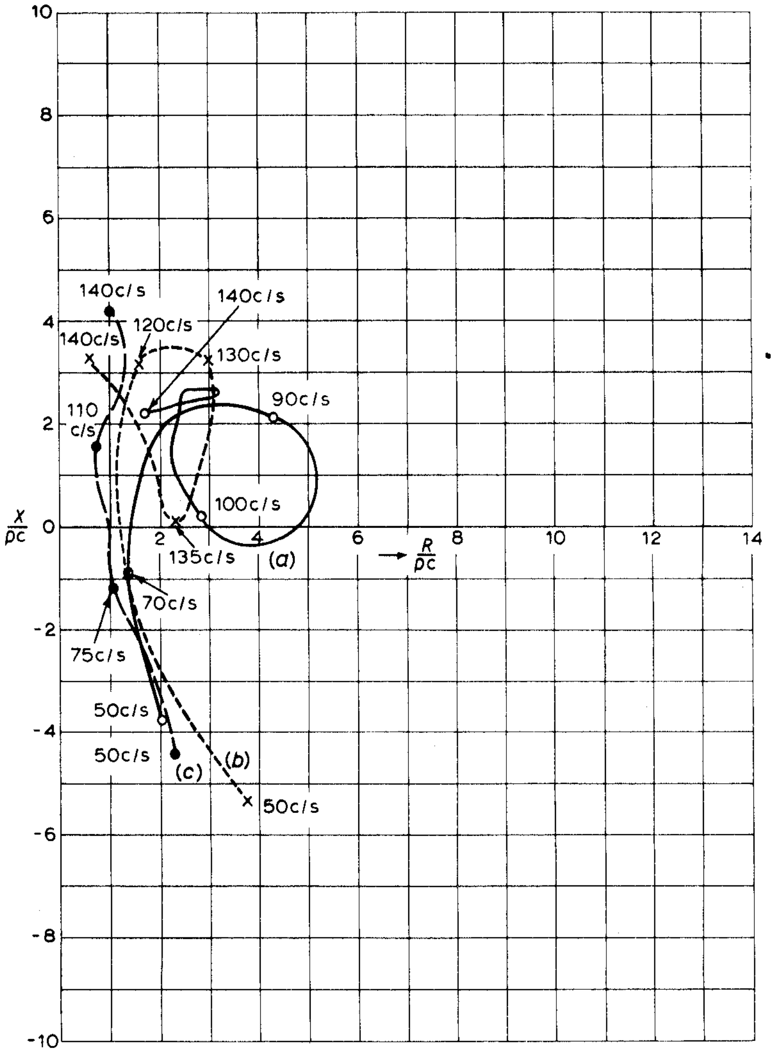

Fig. 4 - Impedance contours for roofing felt over 7 in (180 mm) air space

(*a*) Absorber in duct (*b*) Absorber in room, clear of wall
(*c*) Absorber in room with the rear of the absorber against a wall

The absorber was then placed with its back to the wall and the measurements were repeated. In this condition the secondary resonance was eliminated, Fig. 4 curve (*c*).

4. EXAMPLE OF USE

The absorption bandwidth of membrane and bonded absorbers can be increased at the expense of peak absorption coefficient by placing a sheet of porous material inside the absorber close to the membrane. A 1 in (25 mm) thick sheet of polyurethane foam was introduced into two different absorbers in turn, and the impedance loci were obtained by the method described above. It is to be expected that the effect of the porous material will be two-fold.

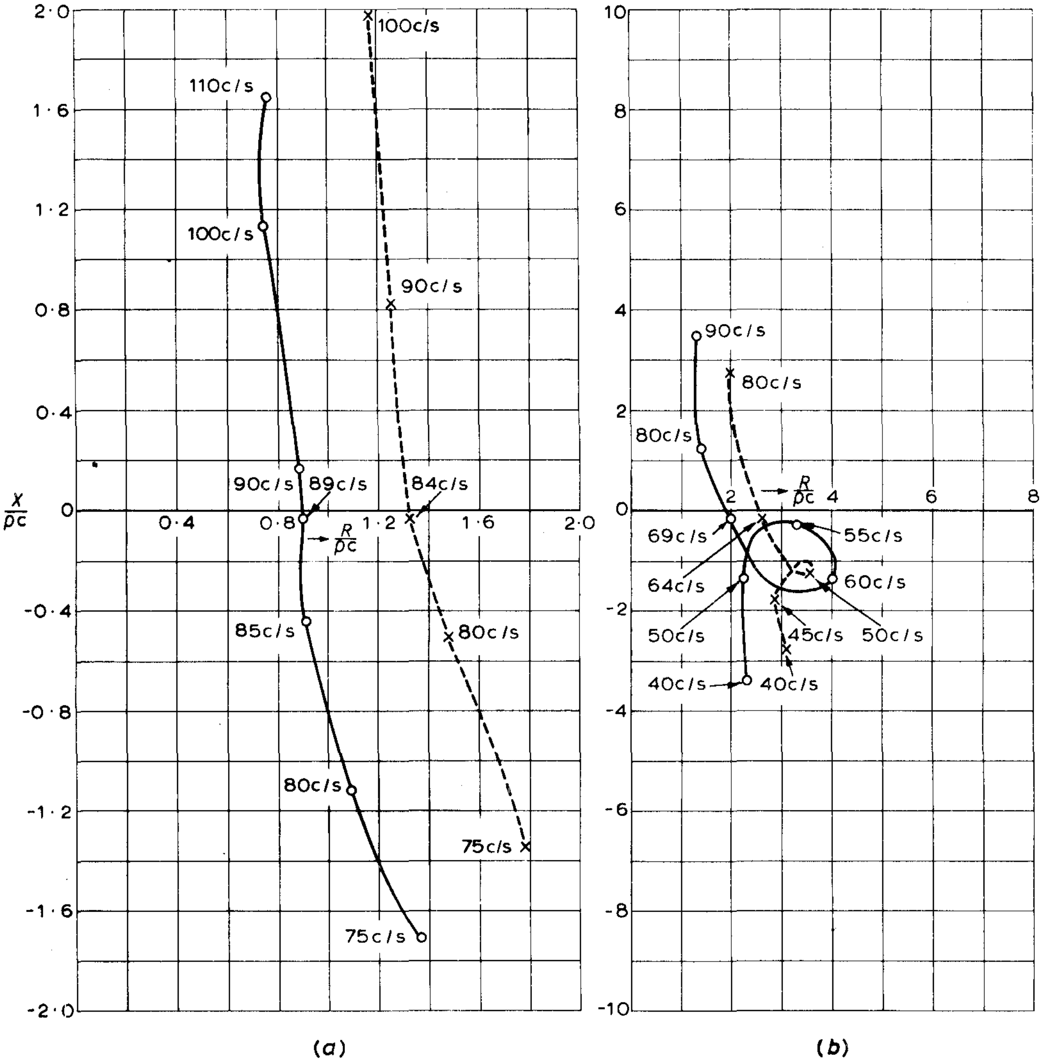

Fig. 5 - Impedance contours of various constructions
(a) Roofing felt over 7 in (180 mm) air space
(b) Aquaplas-coated steel sheet over 7 in (180 mm) air space

o——o Undamped x------x Damped with 1 in (25 mm) Polyurethane foam

First, since the velocity of sound in the air spaces in the porous material is less than in free air the resonance frequency of the absorber will be lowered.

Secondly, the real part of the impedance should be increased at all frequencies by the same amount. Figs. 5(*a*) and 5(*b*) show the impedance loci obtained for the two absorbers.

It will be noticed that the impedance locus in each case is displaced along the resistance axis by the same amount and that the frequency of resonance has been lowered by the introduction of damping material into the absorber.

5. CONCLUSIONS

A simple method of measuring the effective specific acoustic impedance of low frequency membrane-type absorbers has been developed. The method gives good agreement with the results obtained from impedance tube measurements, and has been shown to be valid when the measurements are carried out in conditions of non-normal incidence.

It should therefore be possible, using a probe microphone and phase meter to obtain a measurement of the acoustic impedance of a membrane absorber in its position in a studio and hence determine its absorption coefficient.

6. REFERENCES

1. GILFORD, C.L.S.: 'Membrane Sound Absorbers and their application to Broadcasting Studios', BBC Quarterly, 1952-3, 7, 4, pp. 246 - 256.
2. BERANEK, L.L.: 'Acoustic Measurements', (New York, John Wiley; London, Chapman and Hall 1949), p. 317.

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